Technical risk factors for portal vein reconstruction thrombosis in pancreatic resection

Natalia O. Glebova, MD, PhD,[a] Caitlin W. Hicks, MD, MS,[b] Kristen M. Piazza, MSPAS, PA-C,[b] Christopher J. Abularrage, MD,[b] Andrew M. Cameron, MD, PhD,[c] Richard D. Schulick, MD, MBA,[d] Christopher L. Wolfgang, MD, PhD,[e] and James H. Black III, MD,[b] *Aurora, Colo; and Baltimore, Md*

Objective: Vascular reconstruction can facilitate pancreas tumor resection, but optimal methods of reconstruction are not well studied. We report our results for portal vein reconstruction (PVR) for pancreatic resection and determinants of postoperative patency.

Methods: We identified 173 patients with PVR in a prospective database of 6522 patients who underwent pancreatic resection at our hospital from 1970 to 2014. There were 128 patients who had >1 year of follow-up with computed tomography imaging. Preoperative, intraoperative, and postoperative factors were recorded. Patients with and without postoperative PVR thrombosis were compared by univariable, multivariable, and receiver operating characteristic curve analyses.

Results: The survival of patients was 100% at 1 month, 88% at 6 months, 66% at 1 year, and 39% on overall median follow-up of 310 days (interquartile range, 417 days). Median survival was 15.5 months (interquartile range, 25 months); 86% of resections were for cancer. Four types of PVR techniques were used: 83% of PVRs were performed by primary repair, 8.7% with interposition vein graft, 4.7% with interposition prosthetic graft, and 4.7% with patch. PVR patency was 100% at 1 day, 98% at 1 month, 91% at 6 months, and 83% at 1 year. Patients with PVR thrombosis were not significantly different from patients with patent PVR in age, survival, preoperative comorbidities, tumor characteristics, perioperative blood loss or transfusion, or postoperative complications. They were more likely to have had preoperative chemotherapy (53% vs 9%; $P <$ .0001), radiation therapy (35% vs 2%; $P <$ .0001), and prolonged operative time (618 ± 57 vs 424 ± 20 minutes; $P =$ .002) and to develop postoperative ascites (76% vs 22%; $P <$ .001). Among patients who developed ascites, 38% of those with PVR thrombosis did so in the setting of tumor recurrence at the porta detected on imaging, whereas among patients with patent PVR, 50% did so ($P =$ .73). Patients with PVR thrombosis were more likely to have had prosthetic graft placement compared with patients with patent PVRs (18% vs 2.7%; $P =$ .03; odds ratio [OR], 7.7; 95% confidence interval [CI], 1.4-42). PVR patency overall was significantly worse for patients who had an interposition prosthetic graft reconstruction (log-rank, $P =$ .04). On multivariable analysis, operative time (OR, 1.01; 95% CI, 1.01-1.02) and prosthetic graft placement (OR, 8.12; 95% CI, 1.1-74) were independent predictors of PVR thrombosis (C statistic = 0.88).

Conclusions: Long operative times and use of prosthetic grafts for reconstruction are risk factors for postoperative portal vein thrombosis. Primary repair, patch, or vein interposition should be preferentially used for PVR in the setting of pancreatic resection. (J Vasc Surg 2015;62:424-33.)

Pancreatic cancer is a deadly disease with an overall 5-year survival rate of 6%, a rising incidence and death rate, and no significant improvement in survival in recent years.[1] Surgical resection is the mainstay of treatment

From the Section of Vascular Surgery and Endovascular Therapy[a] and Division of GI, Tumor, and Endocrine Surgery,[d] Department of Surgery, University of Colorado Denver, Aurora; and the Division of Vascular Surgery and Endovascular Therapy,[b] Division of Transplant Surgery,[c] and Division of Surgical Oncology,[e] Department of Surgery, Johns Hopkins Hospital, Baltimore.

and, in combination with neoadjuvant chemoradiation, results in a 5-year survival rate of 28%.[2] As surgical resection provides the best chance for survival for patients with pancreatic cancer, aggressive removal of locoregionally advanced disease is increasingly advocated.

Involvement of the portal vein by tumor happens not infrequently in patients with pancreatic cancer and has been considered in the past to be a sign of advanced disease stage and unresectability. From this perspective, portal vein resection and portal vein reconstruction (PVR) during pancreatectomy for malignant disease were historically deemed to be not beneficial for a patient's survival.[3]

More recently, several retrospective studies have shown that in appropriately selected patients who receive an R0 resection, the morbidity, mortality, and survival rates for patients who undergo portal vein resection and PVR in the setting of pancreatic cancer removal are similar to those for patients who do not require PVR.[4-6] Although some debate still exists in light of other studies showing increased complications after PVR in the setting of pancreatectomy,[6,7] PVR is currently an acceptable technique during pancreatic resection when tumor is locally advanced and involves the portal vein.

However, the optimal methods of PVR during pancre-atectomy for tumor are not well established. To address this question, we used our extensive institutional experience with pancreatic cancer resection and analyzed our results for PVR in the setting of pancreatectomy to ascertain the determinants of postoperative reconstruction patency.

METHODS

Patient selection. We performed a retrospective review of a prospectively maintained institutional database of all pancreatectomies performed at the Johns Hopkins Hospital between 1970 and 2014. Informed consent for performance of clinical research was obtained from the patient at the time of the procedure. This work was approved by our Institutional Review Board.

Of 6522 available patients, we identified 173 patients who underwent a concomitant portal vein resection. We then excluded intraoperative deaths (1 patient), early post-operative deaths <6 months after the operation (23 patients), and patients with follow-up of <6 months (11 patients) or 1 year (10 patients). We excluded these early deaths because they were not clearly related to thrombosis of PVR as none of these patients had postoperative PVR thrombosis. Causes of death were progression of malignant disease with metastasis (9), unknown cause after uneventful discharge to home in a different state (7), postoperative cardiac arrest secondary to sepsis in the setting of anastomotic leak (4), cardiac arrest secondary to hemorrhage (2), respiratory failure (1), and stroke (1). There were 128 patients with >1 year of follow-up with computed tomography (CT) imaging who were thus available for analysis (Fig 1).

The protocol for regular follow-up was CT scan at 6 months and at 1 year. Most thromboses were found on routine follow-up CT scanning for evaluation of malignant disease. Seven of 17 patients with PVR thromboses had documented open reconstructions on earlier postoperative CT scans. Most preoperative, intraoperative, and postoperative factors had been abstracted previously from electronic clinical records by independent database personnel. In addition, we reviewed postoperative CT scans to identify PVR thrombosis. We then compared patients with PVR thrombosis with those patients whose PVR remained patent using univariable, multivariable, and receiver operating characteristic curve analyses.

Details of PVR. The primary reconstruction group included 41 primary end-to-end anastomoses and 64 lateral venorrhaphies. Patches used were autologous vein (3), bovine pericardial (2), and Gore-Tex (1). For vein interposition, we used internal jugular (4), left renal (4), splenic (2), and great saphenous (1) vein. For synthetic grafts, we used 8-mm Dacron (1) and polytetrafluoroethylene (PTFE; four ringed and one nonringed). Primary lateral venorrhaphy was performed if the degree of luminal narrowing was not >30%. If >30% of the portal vein lumen was compromised, we performed primary end-to-end repair, if mobilization of the portal vein was possible, or repair with patch or interposition graft. Primary anastomosis was performed usually if the length was <2 cm. Several maneuvers were used to achieve primary reconstruction. In the primary end-to-end

anastomosis group, four patients had extensive mobilization of the root of the mesentery; seven patients, of the right colon; three patients, of the ligaments of the liver; and two patients, of both the root of the mesentery and the right colon. We ligated the splenic vein in the majority of the primary reconstruction patients: in 78% of the patients (32 of 41) with primary end-to-end PVR, and in 33% of the patients (21 of 64) with lateral venorrhaphy. Two patients in the primary end-to-end PVR group developed sinistral hypertension (3.8% of all patients with ligated splenic vein), and one of these two had a gastrointestinal bleed secondary to erosive esophagitis. No patients underwent syndactylization with the superior mesenteric vein, reimplantation of the splenic vein, or translocation to the left renal vein. In general, 50% of circumference was resected when patch reconstruction was used. Interposition graft reconstruction was necessitated on average when the length of portal vein resected was >2 cm and the luminal compromise was >30%. The conduit choice was based on the surgeon's preference and the stability of the patient, with more urgent clinical condition leading to the use of prosthetic graft to decrease the operative time. Intraoperative anticoagulation with heparin was not used routinely intraoperatively or postoperatively. There were two patients who were anticoagulated postoperatively with PVR as the indication. One patient with primary reconstruction was anticoagulated because of narrowing of the portal vein-superior mesenteric vein confluence on postoperative CT, and this patient did not suffer PVR thrombosis. One patient in the interposition graft group was anticoagulated postoperatively because of the presence of portal vein thrombus on CT, and the reconstruction went on to thrombose in this patient on follow-up. Superior mesenteric artery flow occlusion and venovenous bypass were not used.

Statistical analysis. Descriptive data are reported as mean ± standard error of the mean, median (interquartile range [IQR]) when the variable was not normally distributed, or count with percentage as appropriate. Univariable analyses were performed by Student t-tests (continuous variables) and Pearson χ^2 or Fisher exact test (categorical variables). Survival analyses were performed by the Kaplan-Meier method, and medians were compared with the log-rank test. Multivariable analysis including all variables identified as significant on univariable analysis was performed by forward stepwise logistic regression modeling ($P \leq .25$ to enter, $P \geq .10$ to remove) to identify risk factors associated with PVR thrombosis. The accuracy of the final model was assessed by a receiver operating characteristic curve. All statistical analyses were performed with JMP 9.0 (SAS Institute, Cary, NC), with statistical significance defined as $P \leq .05$.

RESULTS

Patient characteristics. There were 128 patients who underwent PVR during pancreatectomy and had >1 year of follow-up with available CT imaging. Of these patients, 17 developed PVR thrombosis and 111 had PVRs that remained patent. Median follow-up was 200 days (IQR, 263
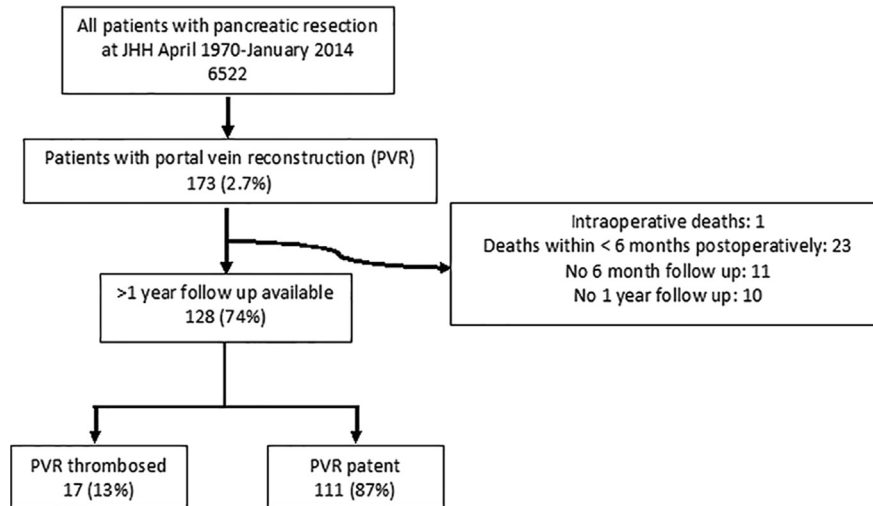
Fig 1. Study design and patient selection. *JHH,* Johns Hopkins Hospital; *PVR,* portal vein reconstruction.

days) for the PVR thrombosed group and 190 days (IQR, 432 days) for the PVR patent group (*P* = .47; Fig 1).

Patients with PVR thrombosis were not significantly different from patients with patent PVR in terms of age, sex, race, and medical comorbidities; presenting symptoms, such as abdominal pain, jaundice, and weight loss; presence of preoperative biliary endostent; and operation performed for malignant vs benign disease (Table I). Patients with PVR thrombosis were more likely to have had preoperative chemotherapy (53% vs 9%; *P* < .0001) and radiation therapy (35% vs 1.8%; *P* < .0001). The use of postoperative chemotherapy and radiation therapy was similar (Table I).

Tumor characteristics. Tumor characteristics including size, grade, number of positive lymph nodes, total number of lymph nodes, and presence of vascular and perineural invasion were similar between the two groups (Table II). Patients who had PVR thrombosis were more likely to undergo an R2 resection (19% vs 0.9%; *P* = .01) and to have a positive specimen pancreas margin (41% vs 11%; *P* = .04) compared with patients with patent PVR. American Joint Committee on Cancer TNM staging was similar between groups (Table II).

Operative characteristics. Patients with PVR thrombosis were more likely to have had a classic Whipple (76% vs 42%; *P* = .01) than a pylorus-preserving pancreaticoduodenectomy compared with patients with patent PVR. Lengths of stay in the intensive care unit and overall were similar (Table III). There were no significant differences in intraoperative blood loss (2957 ± 1062 vs 2371 ± 408 mL; *P* = .61) and number of transfusions (4.9 ± 2.68 vs 3.78 ± 0.89 units of packed red blood cells; *P* = .69) between the PVR thrombosed and PVR patent groups, respectively (Table III). Operative time was significantly longer for the PVR thrombosed group (618 ± 57 vs 424 ± 20 minutes; *P* = .002; Table III).

Postoperative complications. There were no significant differences in the incidence of postoperative complications between the PVR thrombosed and PVR patent groups, including delayed gastric emptying, small bowel obstruction, pancreatic fistula, lymph leak, mesenteric venous thrombosis, wound complications, abscess formation, cardiac events, and respiratory complications (Table IV). There were nonsignificant trends toward more frequent anastomotic leaks (11.8% vs 1.8%; *P* = .09) and postoperative bleeding (23.5% vs 9%; *P* = .09) in the PVR thrombosed group (Table IV).

Patient survival. The survival of patients was 100% at 1 month, 88% (112 of 128) at 6 months, 66% (84 of 128) at 1 year, and 39% (50 of 128) on overall median follow-up of 310 days (IQR, 417 days; Fig 2). Median survival was 15.5 months (IQR, 25 months). Survival was similar between patients with PVR thrombosis and those with patent PVR (Table V).

Four types of PVR techniques were used: 83% of PVRs were performed by primary repair, 8.7% with interposition vein graft, 4.7% with interposition prosthetic graft, and 4.7% with patch (Fig 3; Table VI). The survival of patients did not differ at 6 months or overall between the four different reconstruction-type groups (log-rank, *P* = .65 and .12, respectively). At 1 year, survival was significantly worse for patients who had an interposition prosthetic graft reconstruction (log-rank, *P* = .009; Fig 2, *A*).

Long-term postoperative outcomes. PVR patency overall was 100% at 1 day, 92% at 1 month, 68% at 6 months, and 43% at 1 year. Patients with PVR thrombosis were more likely to develop postoperative ascites (76% vs 22%; *P* < .001). Among patients with PVR thrombosis who developed ascites, 38% did so in the setting of tumor recurrence at the porta detected on imaging. Among patients with patent PVR who developed ascites, 50% did so in the setting of tumor recurrence (*P* = .73) (Table V).

Six (35%) of the PVR thromboses occurred in the setting of tumor recurrence at the porta, and the mean time to detection of thrombosis in these patients was

Table I. Patient characteristics

Patient characteristic	PVR thrombosed (n = 17; 13%)	PVR patent (n = 111; 87%)	P value
Age, years, mean ± SEM	65 ± 3.0	63 ± 1.2	.57
Sex, male	11 (65)	60 (54)	.41
Race, white	15 (88)	93 (84)	.70
Median survival, months (IQR)	7.4 (7.7)	11.5 (15.2)	.16
Median postoperative follow-up, days (IQR)	200 (432)	190 (263)	.47
Median time to follow-up imaging, days (IQR)	193 (263)	158 (400)	.41
Patient comorbidities			
Coronary artery disease	1 (5.8)	9 (8.1)	1
Hypertension	6 (35)	40 (36)	1
Past smoker	5 (29)	26 (23.4)	.59
Current smoker	1 (5.8)	9 (8.1)	1
Renal insufficiency	1 (5.8)	3 (2.7)	.44
Hyperlipidemia	3 (17.6)	13 (11.7)	.45
Diabetes mellitus	5 (29)	27 (25)	.67
Liver disease	0 (0)	1 (0.9)	1
Pulmonary disease	0 (0)	1 (0.9)	1
Preoperative factors			
Presentation with abdominal pain	6 (35.3)	48 (43.2)	.52
Jaundice	7 (41.2)	54 (49)	.57
Weight loss	3 (18)	30 (27)	.40
Preoperative chemotherapy	9 (53)	10 (9)	<.0001
Preoperative radiation therapy	6 (35)	2 (1.8)	<.0001
Postoperative chemotherapy	4 (24)	19 (17)	.53
Postoperative radiation therapy	0 (0)	3 (2.7)	.35
Preoperative biliary endostent	5 (29)	38 (34)	.68
Operation for cancer (vs benign lesion)	14 (82)	96 (86)	.47

IQR, Interquartile range; *PVR*, portal vein reconstruction; *SEM*, standard error of the mean.
Data are presented as number (%) unless otherwise indicated.

202.6 ± 60 days. Eleven (65%) of the PVR thromboses occurred without documented tumor recurrence at a mean of 80.1 ± 25.8 days (P = .04). The time to diagnosis of PVR thrombosis was significantly longer for patients who developed thrombosis in the setting of tumor recurrence compared with those who did not recur (202.6 ± 147 vs 80 ± 86 days; P = .04).

Patients with PVR thrombosis were more likely to have had prosthetic graft placement compared with patients with patent PVRs (18% vs 2.7%; P = .03; odds ratio [OR], 7.7; 95% confidence interval [CI], 1.4-42; Table VI). Patency was significantly worse at 6 months and on overall follow-up for patients who had an interposition prosthetic graft reconstruction (log-rank, P = .01 and P = .04, respectively; Fig 2, B). In comparing patency and survival for synthetic interposition graft vs other type of reconstruction, patency was significantly worse but survival was not statistically different between the two groups (P = .01 and .74, respectively; Fig 2, C and D). On multivariable analysis, operative time (OR, 1.01; 95% CI, 1.01-1.02) and prosthetic graft placement (OR, 8.12; 95% CI, 1.1-74) were independent predictors of PVR thrombosis with combined C statistic of 0.88 (Fig 4).

DISCUSSION

The treatment of pancreatic cancer continues to be a challenge, with surgical resection currently providing the only chance for cure, and only 15% to 20% of tumors are resectable at the time of diagnosis.[8] The intimate relationship between the pancreas and the portal structures frequently results in the involvement of the portal vein in pancreatic malignant neoplasms. Such involvement of structures surrounding the head of the pancreas may be a function of anatomic proximity of tumor or may be indicative of a more aggressive and advanced tumor.[9] Thus, controversy has existed in the past regarding the appropriateness of pancreatic resection in the setting of involvement of locoregional structures such as the portal vein.

Some groups have reported reduced survival in patients undergoing pancreas resection with PVR compared with that in patients who do not undergo PVR.[10-12] For example, an analysis of the National Surgical Quality Improvement Program database found increased 30-day morbidity and mortality for patients who receive PVR with pancreatectomy.[7] One study reported increased postoperative complication rates in patients who received PVR,[6] and another reported a higher 30-day mortality rate with comparable overall survival.[9]

However, several more recent studies have documented similar outcomes in both groups of patients.[13-16] Multiple groups have reported that pancreatectomy with PVR prolongs survival in patients with pancreatic cancer.[13,17-20] In one retrospective study, despite the more advanced cancer found in patients who underwent PVR, there was no difference in R0 resection rates and mortality between patients undergoing pancreatic resection with and

Table II. Tumor characteristics

Tumor characteristic	PVR thrombosed (n = 17; 13%)	PVR patent (n = 111; 87%)	P value
Tumor size, cm, mean ± SEM	2.63 ± 0.61	3.52 ± 0.24	.17
Pathology grade[a]			
Well differentiated	0 (0)	7 (8)	.59
Moderately differentiated	7 (58)	42 (49)	.54
Poorly differentiated	5 (42)	37 (43)	1
Vascular invasion[a]	7 (70)	47 (65)	1
Perineural invasion[a]	11 (79)	69 (82)	.72
No. of positive lymph nodes, mean ± SEM[a]	1.25 ± 0.90	2.74 ± 0.36	.12
Total No. of lymph nodes, mean ± SEM[a]	21.2 ± 2.47	21.8 ± 0.98	.81
Resection type[a]			
R0	9 (56)	69 (73)	.16
R1	4 (25)	24 (26)	1
R2	3 (19)	1 (0.9)	.01
Positive pancreatic margin	7 (41)	12 (11)	.04
Pathology: adenocarcinoma	13 (76)	73 (66)	.6
AJCC stage T[a]			.72
T1	0 (0)	4 (4.26)	
T2	0 (0)	14 (14.9)	
T3	8 (53)	40 (42.6)	
T4	1 (6.7)	7 (7.5)	
T5	2 (13.3)	8 (8.5)	
T6	3 (20)	15 (16)	
TX	1 (6.7)	6 (6.4)	
AJCC stage N[a]			.24
N0	2 (13)	23 (25)	
N1	6 (40)	46 (50)	
N2	4 (27)	9 (9.8)	
N3	3 (20)	14 (15)	
AJCC stage M[a]			.16
M0	5 (42)	49 (66)	
M1	3 (25)	4 (5.4)	
M2	3 (25)	12 (16.2)	
M3	0 (0)	1 (1.4)	
MX	1 (8.3)	8 (10.8)	

AJCC, American Joint Committee on Cancer; *M,* metastasis; *N,* lymph nodes; *PVR,* portal vein reconstruction; *R0,* complete tumor resection; *R1,* microscopic residual tumor; *R2,* macroscopic residual tumor; *SEM,* standard error of the mean; *T,* tumor.
Data are presented as number (%) unless otherwise indicated.
[a]Total numbers of patients are inconsistent because of missing data.

without PVR.[21] Not only do patients who undergo PVR have better outcomes than those who receive palliation,[17] but survival for patients who receive complete tumor resection with PVR is comparable to that for patients who undergo pancreatectomy without PVR.[14,16,22,23] If an R0 resection is accomplished, the patient's survival is not adversely affected by the need for PVR.[18] Thus, PVR is a safe and effective method for achieving complete tumor resection during pancreatectomy for malignant disease and imparting a survival benefit to appropriately selected patients with the goal of cure.[5]

A number of retrospective analyses have focused on determining the appropriateness of aggressive PVR during pancreatic cancer resection and have led to the current practice of favoring PVR during pancreatectomy if it is required for tumor removal. However, the optimal type of reconstruction after portal vein resection has not been established. Several options exist: PVR may be accomplished primarily with a partial resection and lateral venorrhaphy, with a circumferential resection and end-to-end anastomosis, or with a circumferential resection and graft interposition (Fig 3). Graft options that have been described include autologous sources such as internal jugular vein,[22] femoral vein,[24] saphenous vein,[25] gonadal vein,[26] left renal vein,[27-29] and external iliac vein[18,30,31] or synthetic graft such as PTFE.[32,33]

A few groups have attempted to examine PVR patency as a function of the type of reconstruction but with limited success because of low numbers of patients.[32] A retrospective review of the use of external iliac and internal jugular vein grafts in 14 patients revealed excellent patency of autologous reconstruction, in contrast to a 3.9% rate of postoperative thrombosis or stenosis of PVR with direct end-to-end anastomosis.[21] Another study found that PTFE reconstruction patency was 100% at 1 month, whereas PVR using vein graft had a patency of 86%, and primary anastomosis had a patency of 60%.[34] Other groups have found prosthetic reconstruction with PTFE to be associated with a 33% rate of thrombosis[35] and a patency rate of 64% at 1 year.[32] Finally, a systematic review of the

Table III. Operative characteristics

Operative characteristic	PVR thrombosed (n = 17; 13%)	PVR patent (n = 111; 87%)	P value
Median length of stay, days (IQR)	10 (6)	11 (12)	.85
Median ICU length of stay, days (IQR)	1 (1.5)	2 (4)	.28
Type of operation			
Classic Whipple	13 (76)	47 (42)	.01
Pylorus-preserving pancreaticoduodenectomy	2 (12)	30 (27)	.24
Total pancreatectomy	1 (5.8)	8 (7.2)	1
Distal pancreatectomy	0 (0)	10 (9)	.36
Blood loss, mL, mean ± SEM	2957 ± 1062	2371 ± 408	.61
Transfusion, packed red blood cell units, mean ± SEM	4.90 ± 2.68	3.78 ± 0.89	.69
Operative time, minutes, mean ± SEM	618 ± 57	424 ± 20	.002
Concomitant SMV resection	4 (24)	25 (23)	1
Concomitant arterial resection	0 (0)	2 (1.8)	1

ICU, Intensive care unit; *IQR,* interquartile range; *PVR,* portal vein reconstruction; *SEM,* standard error of the mean; *SMV,* superior mesenteric vein.
Data are presented as number (%) unless otherwise indicated.

Table IV. Early postoperative complications

Postoperative complication	PVR thrombosed (n = 17; 13%)	PVR patent (n = 111; 87%)	P value
Delayed gastric emptying	1 (5.9)	15 (13.5)	.69
Small bowel obstruction	0 (0)	3 (2.7)	1
Pancreatic fistula	2 (11.8)	14 (12.6)	1
Biliary, duodenal, gastrojejunostomy leak	2 (11.8)	2 (1.8)	.09
Lymph leak	0 (0)	9 (8.1)	.61
Bleeding	4 (23.5)	10 (9)	.09
Mesenteric or venous thrombosis	1 (5.9)	1 (0.9)	.25
Wound complication	2 (11.8)	17 (15)	1
Abscess	3 (17.6)	16 (14.4)	.72
Cardiac event	0 (0)	10 (9)	.36
Respiratory complication	2 (11.8)	10 (9)	.66

PVR, Portal vein reconstruction.
Data are presented as number (%).

available studies on PVR in the literature suggested prosthetic use during PVR to be a risk factor for PVR thrombosis, but this association was not statistically significant because of low numbers of patients.[36]

We report the largest to date single-institution series of patients undergoing PVR during pancreas tumor resection and find that the overall PVR thrombosis rate is 13% and that reconstruction using a prosthetic graft is the main risk factor for PVR thrombosis. Patients who suffer PVR thrombosis are similar to those whose PVR stays patent in preoperative medical comorbidities and tumor characteristics, except for the higher prevalence of preoperative chemoradiation. On resection, tumor characteristics are similar between the two groups except for the higher prevalence of R2 resection and positive pancreatic margins in the PVR thrombosis group, indicating a more advanced stage of tumor. Operative time is longer in patients with PVR thrombosis, but other operative factors, such as length of stay, blood loss, and transfusion, are not different. This suggests that longer operative times are associated with a technically more difficult tumor resection but not increased bleeding. Postoperative complications are similar between the two groups. PVR patency is significantly worse when prosthetic graft is used and correlates with worse survival at 1 year postoperatively. However, overall survival at last follow-up is similar between the PVR thrombosed and patent groups, indicating that factors other than PVR thrombosis are driving mortality in these patients.

Our results are consistent with the work of others who have found no statistically significant differences in survival among patients who had primary venorrhaphy, end-to-end anastomosis, vein patch, or prosthetic graft at 3 years postoperatively.[37] Another study noted no difference in survival among patients who had a lateral venorrhaphy, end-to-end anastomosis, or prosthetic graft.[6] Such lack of survival difference despite significant difference in PVR patency in our patients with prosthetic graft reconstruction implies that a significant driver of mortality is likely to be cancer related and not PVR related. With better neoadjuvant chemoradiation treatments and improvements in cancer-related survival, careful consideration should be given to the technique of PVR as its patency may become more critical for overall survival of patients.
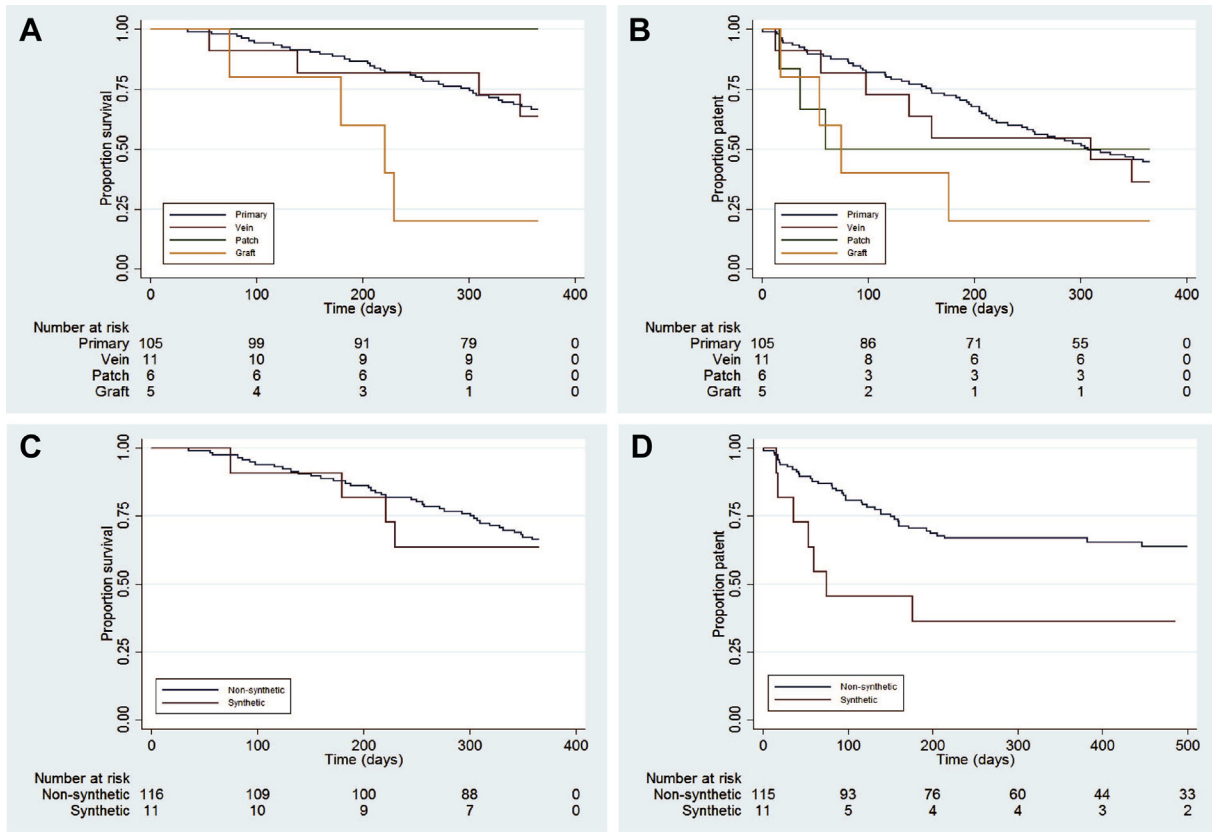
Fig 2. Kaplan-Meier analysis of patient survival **(A)** and patency at 1 year **(B)** stratified by individual portal vein reconstruction (PVR) type and of patient survival **(C)** and PVR patency **(D)** at 1 year comparing synthetic graft reconstruction and nonsynthetic reconstruction.

Table V. Long-term outcomes

Postoperative characteristic	PVR thrombosed (n = 17; 13%)	PVR patent (n = 111; 87%)	P value
Patients alive at 6 months	16 (94)	96 (87)	.69
Patients alive at 1 year	10 (59)	74 (67)	.49
Incidence of postoperative ascites	13 (76)	24 (22)	<.001
Ascites in setting of tumor recurrence	5 (38% of all ascites)	12 (50% of all ascites)	.73

PVR, Portal vein reconstruction.
Data are presented as number (%).

As one would expect, patients with PVR thrombosis are at a higher risk for development of ascites than are those with patent PVR. Interestingly, the percentage of patients who develop ascites in the setting of tumor recurrence is similar between the PVR thrombosed and patent groups, suggesting that tumor recurrence plays the dominant role in ascites development. We noted in our experience that some PVR thromboses occurred in a delayed fashion and in the setting of tumor recurrence, suggesting two pathways to PVR thrombosis: an early one potentially due to technical aspects of the reconstruction, and a late one secondary to tumor recurrence in the porta.

The importance of prevention of acute PVR thrombosis with its devastating consequences of ascites, bowel ischemia, and a mortality rate of 40%[32,36] cannot be understated. One should avoid the use of prosthetic grafts for reconstruction. Vein interposition may be used, and certain techniques may be helpful in mobilizing the structures in the porta to eliminate tension at the PVR anastomoses. For example, mobilization of the right hemicolon may be used to increase mobility of the portal structures and to allow primary anastomosis during PVR.[38] The root of the mesentery may be divided and ligaments of the liver mobilized to avoid the need for graft interposition in long segmental PVR.[39]

It also behooves us to consider that apparent portal vein involvement by tumor noted intraoperatively may in fact be a benign desmoplastic reaction. The frequency of this
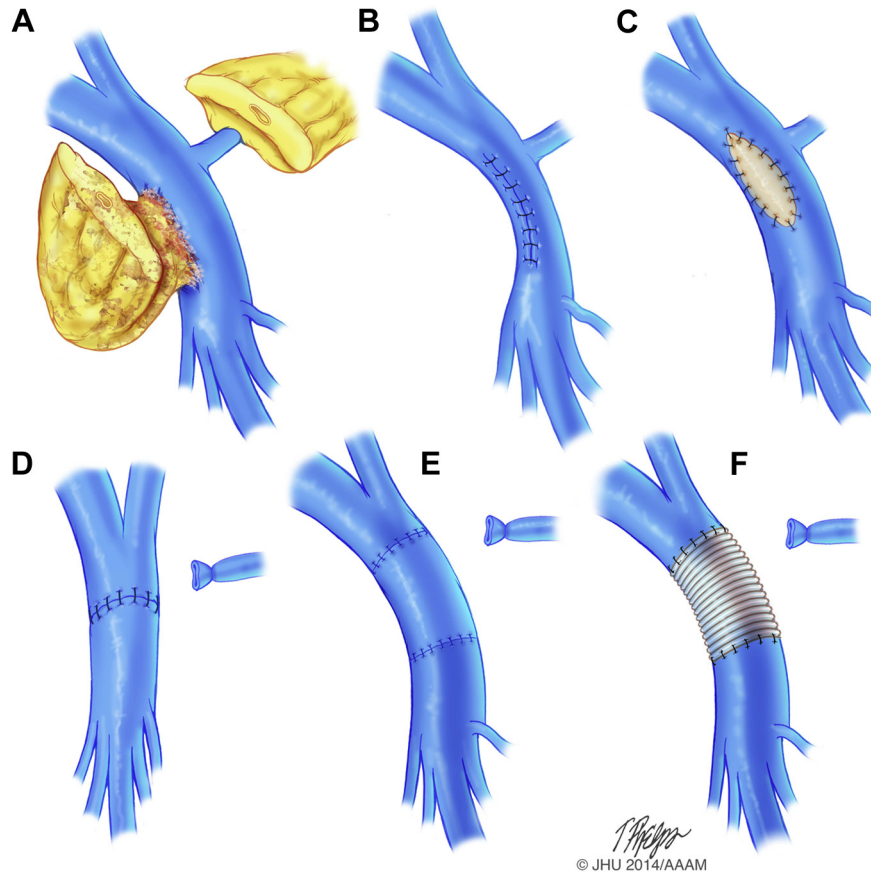
Fig 3. Illustrations showing involvement of the portal vein with tumor originating in the head of the pancreas **(A)** and techniques for portal vein reconstruction (PVR): primary repair by lateral venorrhaphy **(B)**, patch repair **(C)**, primary repair by portal vein mobilization and end-to-end anastomosis **(D)**, vein interposition **(E)**, and prosthetic graft interposition **(F)**.

Table VI. Outcomes of portal vein reconstruction (*PVR*) stratified by the type of reconstruction

Type of reconstruction (total No., % of all PVRs)	PVR thrombosed (n = 17; 13%)	PVR patent (n = 111; 87%)	P value
Primary (105, 83)	12 (71)	93 (85)	.19
Interposition vein (11, 8.7)	1 (6)	10 (9)	1
Interposition graft (6, 4.7)	3 (18)	3 (2.7)	.03
Patch (6, 4.7)	1 (6)	5 (4.6)	.58

Data are presented as number (%).

phenomenon varies; one group noted that up to one fourth of patients who had PVR for apparent portal vein involvement with tumor did not have actual tumor infiltration of the vein,[17] whereas another found that about half of patients who underwent PVR had true tumor infiltration.[9] Patients with such benign desmoplastic reaction benefit greatly from PVR, whereas those who have true tumor infiltration do exhibit worse survival.[12] In those patients with desmoplastic or benign involvement of the vein, attention to technical factors during PVR is critical to ensuring the survival benefit of the operation. In general, better clinical

tools for determining tumor vs benign PVR involvement are needed to identify patients who may benefit from PVR during pancreatectomy for malignant disease.

The limitations of this study include the retrospective nature of the analysis (although the data were collected in prospective fashion) and the heterogeneity in the surgeons' approaches to PVR. Thus, we were unable to control for aspects of decision-making in choosing the method for PVR. In addition, we could not control for tumor and operative characteristics that could have played a role in the surgeon's choice regarding the technique for PVR. For example, a
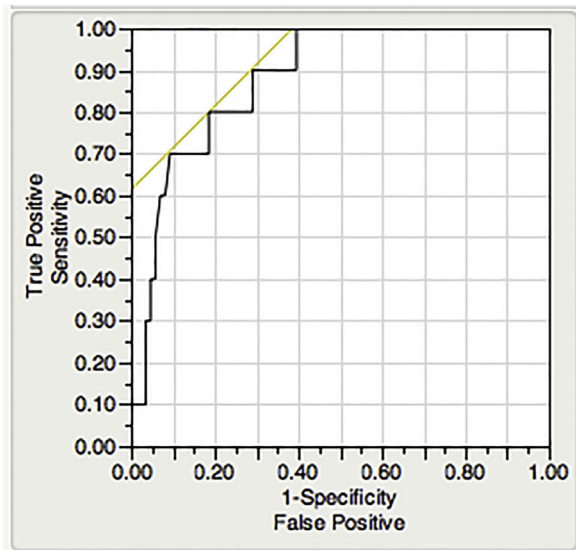
Fig 4. Receiver operating characteristic curve analysis for operative time with graft reconstruction.

longer operative time secondary to a technically difficult tumor resection could have led to the decision to use a prosthetic graft as opposed to an autologous conduit. There were also several patients whose tumor pathology data including American Joint Committee on Cancer staging were incomplete in the database. However, we report herein a large series of patients who underwent PVR, and the number of patients involved allowed us to assess the effects of different PVR techniques on patency. Furthermore, because of our stringent follow-up imaging protocol, we were able to report long-term PVR patency that has been rarely addressed in previous studies as well as the development of ascites related to complications of PVR thrombosis.

CONCLUSIONS

Durable patency may be achieved with PVR during pancreatectomy for malignant disease. Long operative times and use of prosthetic grafts for reconstruction are risk factors for postoperative portal vein thrombosis. Primary or patch repair and vein interposition should be preferentially used for PVR in the setting of pancreatic resection.

AUTHOR CONTRIBUTIONS

Conception and design: NG, CW, JB
Analysis and interpretation: NG, CH, JB
Data collection: NG, KP, CA, AC, CW
Writing the article: NG, RS, CW, JB
Critical revision of the article: NG, CH, KP, JB
Final approval of the article: NG, JB
Statistical analysis: CH
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Overall responsibility: JB

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